[redacted] 7

CONTRACT REQUIREMENTS	CONTRACT ITEM	MODEL	CONTRACT NO.	DATE
EXHIBIT E, PARA 5.1	ENG'R DATA	LEM	NAS 9-1100	3-30-63

TYPE II
CONTRACT LINE ITEM 13.0

REPORT

NO. LED-490-2 DATE: 30 July 1963

PRELIMINARY

LEM MASS PROPERTY REPORT [U]

CODE 26512

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REVISIONS

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GRUMMAN AIRCRAFT ENGINEERING CORPORATION

ENG. 345

LEM

MASS PROPERTIES REPORT

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A GROWTH FACTOR

B PROPELLANT TANK SIZING AND CRITERIA

[redacted]

INTRODUCTION

This report includes the current LEM Weight Status and Target Weight values in addition to some of the major study efforts to date.

The current status, as included in this report, represents a complete rework of all the LEM systems and subsystems, as currently configured in order to meet the LEM work statement and subsequent clarifying directives. The effect of the work statement and directives has caused some major subsystem configuration changes which make it impractical to compare the current weight status to previously reported weights.

In order to clearly present the effect of the LEM current weight status, two performance curves have been included, (Fig. 1 and 2)

The ascent stage (dry) overweight results in a lift-off stage weight of 9798 pounds when the tanks are filled to capacity. However, the tank size limiting point is such that only 6030 fps ΔV is available as compared to the required ΔV of 7079 fps.

7079
6030
req ΔV = 1049 fps

If the descent stage and consumable items (totaling 3511 pounds) are added to the lift-off weight to obtain a touchdown weight, (ref: Figure 2) the following results:

For Separation Weight	Available ΔV
28882 Lbs.	7540 fps
28000 Lbs.	7280 fps
26800 Lbs.	6820 fps

It should be noted that while the performance loss in descent is not as severe as in ascent, the descent performance does not meet the required ΔV of 7827 fps.

The difference between the Target touchdown weight and the current value is attributed to the following:

Ascent stage (dry)	= + 1535 Lbs.
Ascent Propellant	= + 556 Lbs.
Descent stage (dry)	= - 190 Lbs.
	+ 1901 Lbs.

The individual subsystem overweight increments in the ascent stage are included on page 8.

The frequency of changes at this date is such that a complete vehicle functional schematic which is in agreement with the current weights, is not available.

The LEM mass property history included herein is based on the following LEM mission profile.

Mission Phase	Approx. Time
Separation to Touchdown	4 hours
Lunar Stay	24 hours
Lift-off to Dock	2.3
Orbital Contingency	17.7
Total Separation to Dock	48.0 hours

Performance criteria used to calculate the mass property history is included on page 3.

LEM Target Weights were based on the philosophy of maintaining the work statement functional requirements associated with "crew safety" and deviating from the functional requirements associated with "mission success". Additional deviations were also included for LEM "non-essential" equipment. "Non-essential" equipment has been defined as any items on board which do not affect the accomplishment of the LEM mission, (i.e. LEM/Earth data Link, Ranging etc.)

This basic difference in philosophics between the Target and current weights explains much of the distorted pattern of over or underweight of LEM Subsystems as indicated on page 8. In view of this problem, a Target weight re-apportionment will be issued by late August.

MISSION HISTORY OF WEIGHT AND PERFORMANCE

Condition	Current Weight	Current ΔV	Target Weight	Target ΔV	I_{sp}
Earth Launch			25,121		
Separation	28,882		25,500		305
Synchronous Orbit			24,465		
		7,540		7,827	
Hover			12,422		
Touchdown	13,309		11,381		
Lunar Lift-off	9,798		7,707		303
Transfer Orbit (50,000 Ft to 80 Miles)		6,030	3,881	7,079	
Burnout (Docked)	4,962		3,558		300
	4,936		ascent		

7707
3558
4149

11,381
7,707
4,674

LEM PERFORMANCE COMPARISON
ASCENT

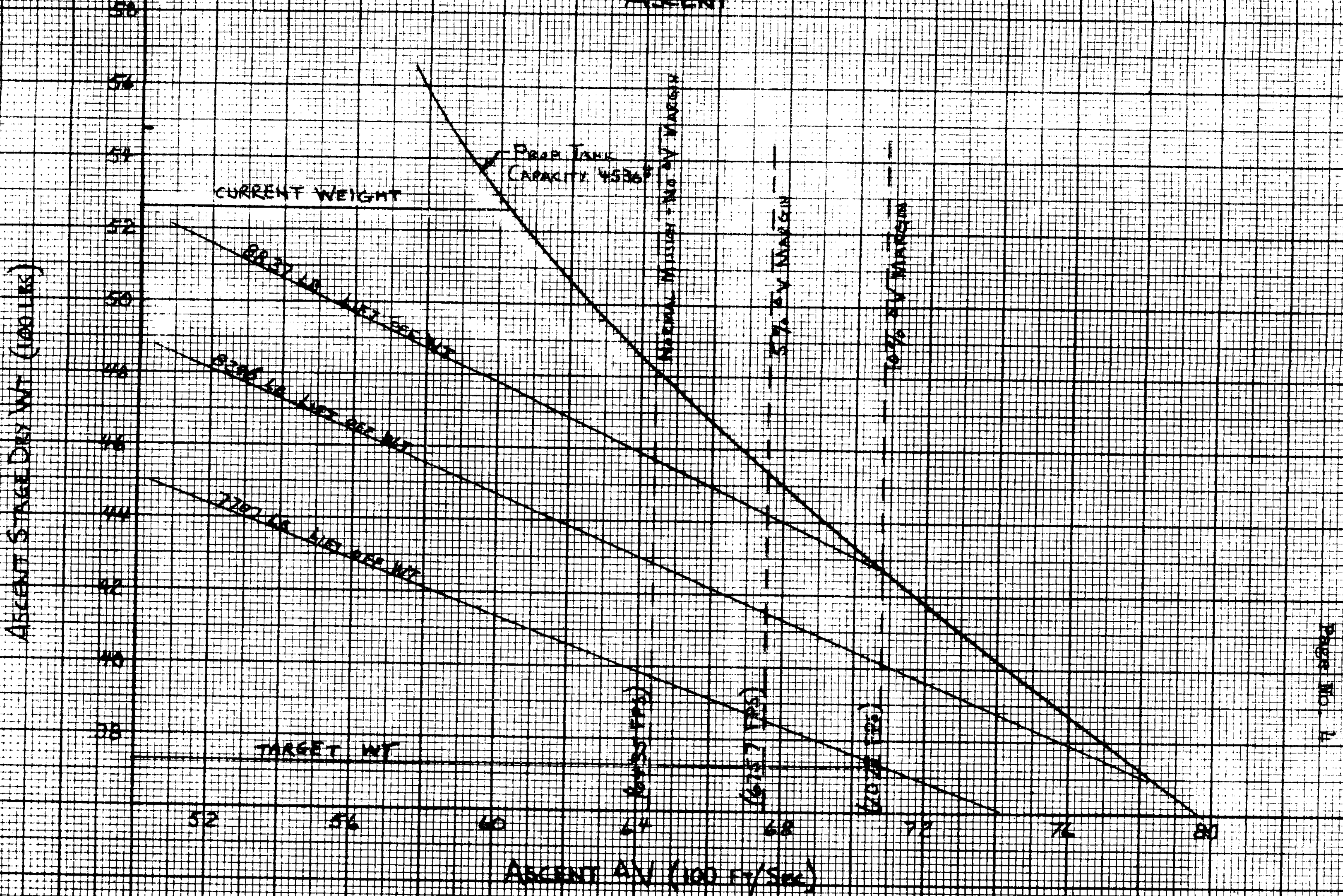


FIG I

LEM PERFORMANCE COMPARISON
DESCENT

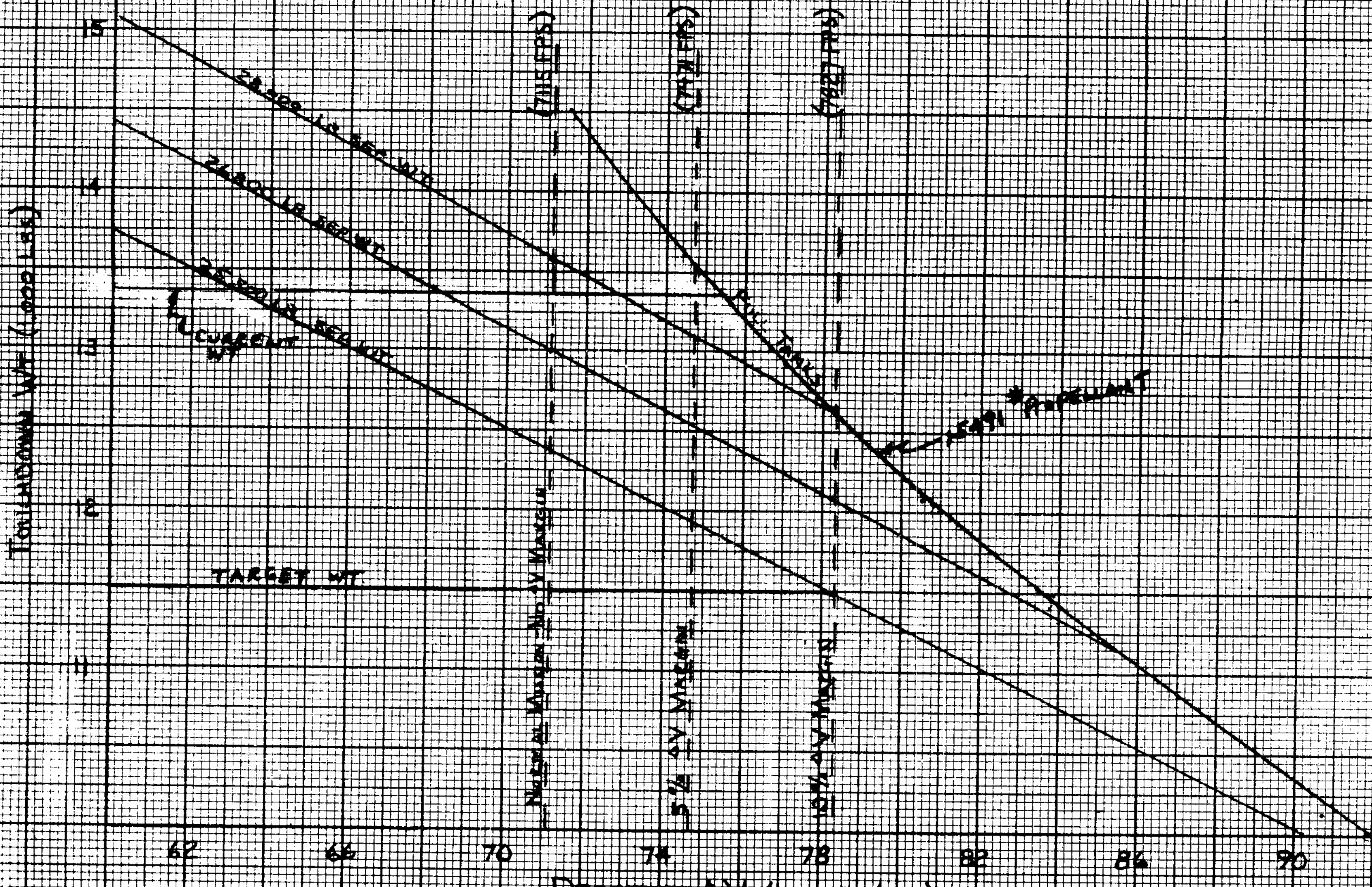
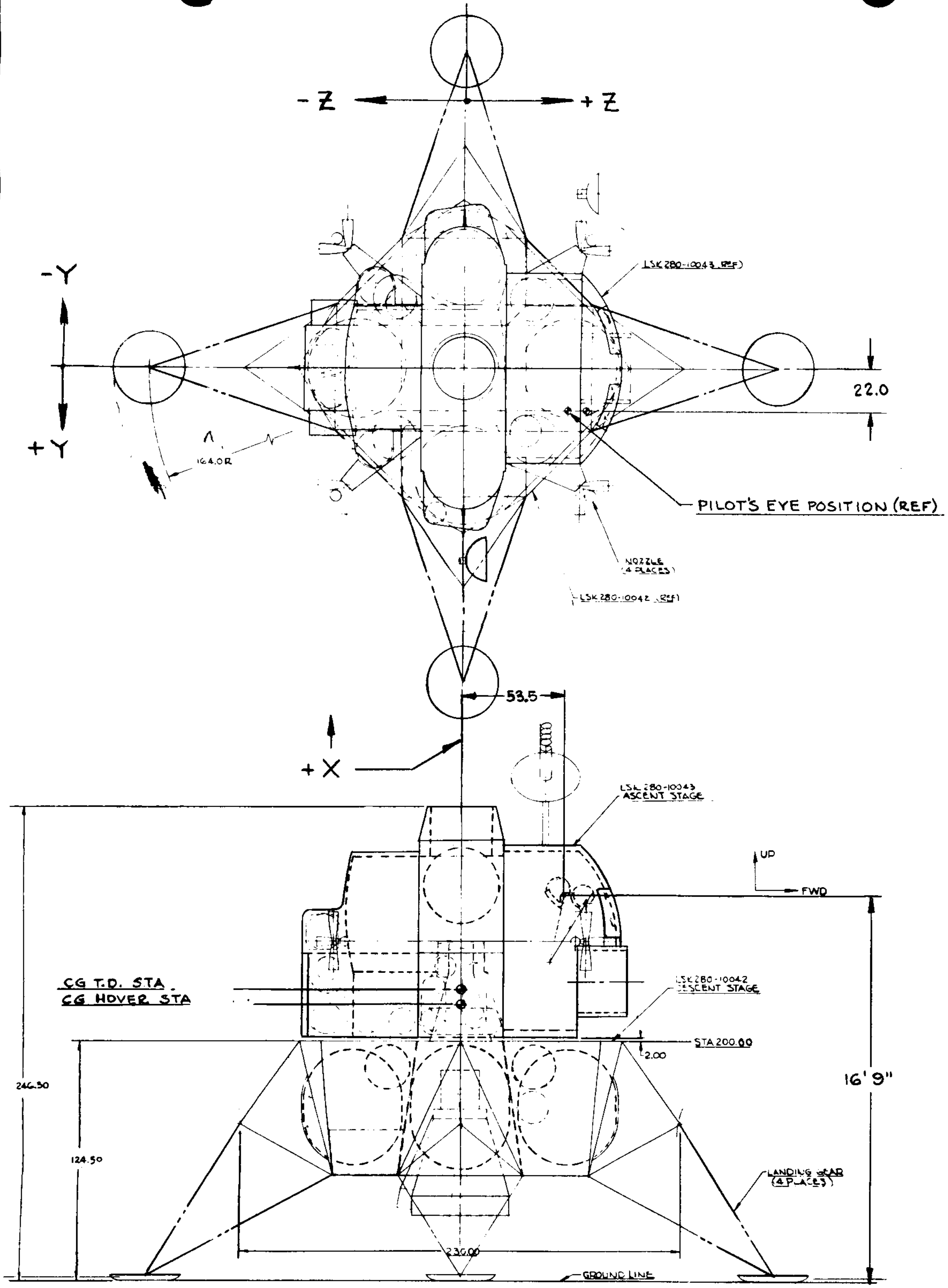
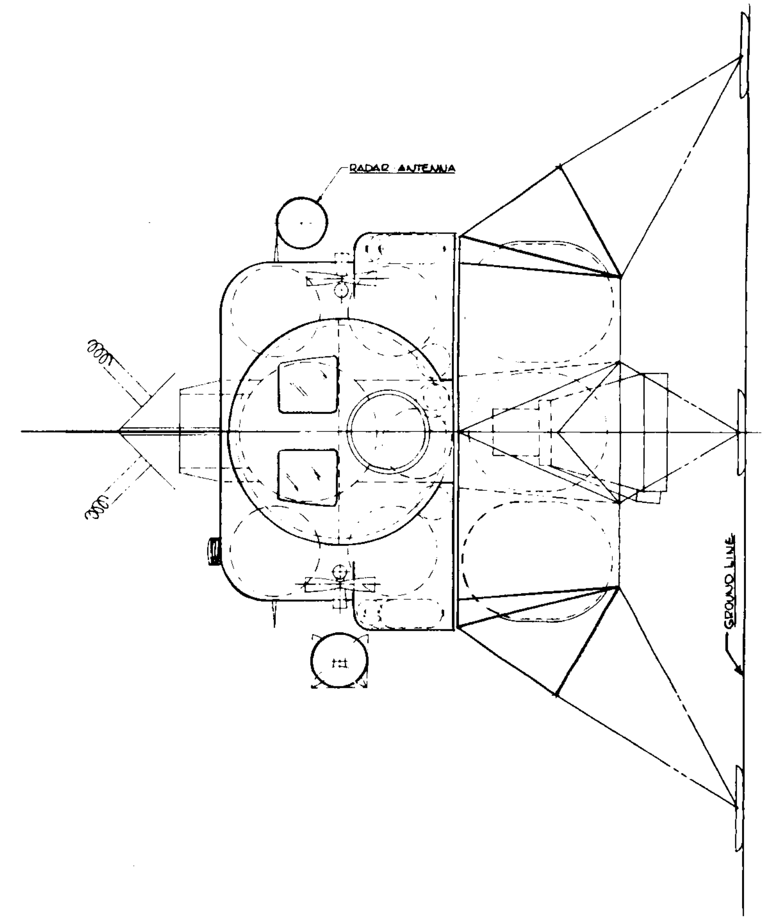


FIG III





LEM AXIS REFERENCE SYSTEM

AND

SIGN CONVENTION

LEM MISSION HISTORY

MASS PROPERTIES BASED ON TARGET WEIGHT

MISSION PHASE	WEIGHT EARTH POUNDS	CENTER OF GRAVITY STATION INCHES	CENTER OF GRAVITY DISTANCE FROM THRUST AXIS		MOMENTS OF INERTIA SLUG FT^2			PRODUCTS OF INERTIA SLUG FT^2		
		X	Y	Z	I_{xx}	I_{yy}	I_{zz}	I_{yz}	I_{xz}	I_{xy}
EARTH LAUNCH	25,121	186.1	-.1	-1.4	16,409	18,767	17,995	-182	-276	16
SEPARATION	25,500	187.8	-.1	- .5	17,277	19,202	18,313	-182	52	18
SYNCHRONOUS ORBIT	24,465	188.0	-.1	- .5	16,567	18,738	18,000	-182	52	18
HOVER	12,422	212.4	-.2	-1.0	8,303	10,146	11,105	-183	119	32
TOUCHDOWN	11,381	218.6	-.2	-1.1	7,618	8,503	9,590	-183	135	35
PRE-LIFT OFF	11,219	218.8	0	-1.0	7,541	8,437	9,497	-183	140	11
LIFT OFF	7,707	245.4	.1	-1.5	4,508	2,793	3,885	- 80	221	-10
TRANSFER ORBIT (50,000 Ft. to 80 Miles)	3,881	244.4	.2	-2.9	2,515	2,173	1,405	- 80	218	-10
BURNOUT (DOCKED)	3,558	245.9	.2	-3	2,209	2,134	1,073	- 80	221	-10
POST-BURNOUT	3,000	244.5	.3	-10.5	1,880	1,797	952	- 79	179	-10

LEM WEIGHT COMPARISON

AT SEPARATION BY STAGES

SUBSYSTEM CODE	ITEM	CURRENT	WEIGHT TARGET	Δ WEIGHT
A.	Ascent Stage Weight at Separation	9942.2 ~~9998.7~~	~~7930.7~~	~~2068.0~~
1.0	Structure	1250.0	812.0	438.0
2.0	Stabilization and Control	104.0 ~~127.5~~	93.0 ~~108.0~~	~~19.5~~ 11.0
3.0	Navigation and Guidance	374 ~~407.0~~	209.0 ~~249.0~~	~~158.0~~ 165.0
4.0	Crew Systems	586.4	558.0	28.4
5.0	Environmental Control	523.5	415.5	108.0
6.0	Landing Gear	--	--	--
7.0	Instrumentation - Operational	389.3	241.0	148.3
	- Scientific	--	--	--
8.0	Electrical Power Supply	676.5	474.0	202.5
9.0	Propulsion System	(4890.4)	(4353.0)	(537.4)
	Propulsion Inert	561.4	516.0	45.4
	Propellant - Usable	4329.0	3837.0	492.0
10.0	Reaction Control	(789.6)	(443.2)	(346.4)
	Propulsion Inert	313.6	160.2	153.4
	Propellant - Usable	476.0	283.0	193.0
11.0	Communications	79.4	38.0	41.4
12.0	Controls and Displays	238.1	198.0	40.1
13.0	Spares	41.0	41.0	0
B.	Descent Stage at Separation	18939.3 ~~18883.8~~	17612.5 ~~17569.5~~	1327.3 ~~1313.8~~
1.0	Structure	737.0	731.0	6.0
4.0	Crew Systems (Landing Lights)	10.0	10.0	0
6.0	Landing Gear - Fixed	603.0	609.0	-6.0
7.0	Instrumentation - Operational	49.0	45.0	4.0
	- Scientific	250.0	250.0	0
8.0	Electrical Power Supply	146.2	63.5	82.7
9.0	Propulsion System	(17066.6)	(15800.0)	(1266.6)
	Propulsion Inert	1592.6	1806.0	-213.4
	Propellant - Usable	15474.0	13994.0	1480.0
11.0	Communications (Portable)	21.5	61.0	- 39.5
C.	Total Separation Weight (A + B)	28882.0	25500.2	3381.8

Report No. LED-490-2
Date 30 July 1963

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LEM
SUMMARY WEIGHT STATEMENT
(BY TIME EVENTS)

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT (at docking) ascent	CONS'D ON ASCENT	JET. ON LURAIN descent	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
1.0	Structure	1250.0		737.0		1987.0	812.0		731.0		1543.0
2.0	Stabilization & Control	104.0		23.5		127.5	93.0		15.0		108.0
3.0	Navigation & Guidance	374.0		33.0		407.0	221.0		28.0		249.0
4.0	Crew Systems	580.8		15.6		596.4	552.0		16.0		568.0
5.0	Environmental Control	290.9	85.2	126.4	21.0	523.5	186.4	61.6	137.5	30.0	415.5
6.0	Landing Gear			603.0		603.0			609.0		609.0
7.0	Instrumentation	(469.2)		(219.1)		(688.3)	(321.0)		(215.0)		(536.0)
	- Operational	389.2		49.1		438.3	241.0		45.0		286.0
	- Scientific	80.0		170.0		250.0	80.0		170.0		250.0
8.0	Electrical Power Supply	659.2	~~17.3~~	138.7	7.5	822.7	419.4	18.6	55.1	44.4	537.5
9.0	Propulsion System	561.4	4329.0	1592.6	15474.0	21957.0	516.0	3837.0	1806.0	13994.0	20153.0
	Inert	515.4		1429.6		1945.0	470.0		1643.0		2113.0
	Propellant	46.0	4329.0	163.0	15474.0	20012.0	46.0	3837.0	163.0	13994.0	18040.0
10.0	Reaction Control	313.6	405.0		71.0	789.6	160.2	232.0		51.0	443.2
11.0	Communications	79.4		21.5		100.9	38.0		61.0		99.0
12.0	Controls & Displays	238.1				238.1	198.0				198.0
13.0	Spares	41.0				41.0	41.0				41.0
	Column Totals	4961.6	4836.5 4961.6	3510.4	15573.5	28882.0	3558.0	4149.2	3673.6	14119.4	25500.2

9798.1
4329
5469

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LEM
DETAIL WEIGHT STATEMENT

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
1.0	Structure	1250.0		737.0		1987.0	812.0		731.0		1543.0
1.1	Crew Compartment	(697.0)				(697.0)	(459.0)				(459.0)
1.1.1	Skin (incl. shielding)	180.0				180.0	135.0				135.0
1.1.2	Frames, Long., Stiffeners	109.0				109.0	93.0				93.0
1.1.3.1	Windows	52.0				52.0	35.0				35.0
1.1.3.2	Window Shades	8.0				8.0	5.0				5.0
1.1.3.3	Window Frames	40.0				40.0	-				-
1.1.4.1	Docking Tube - Upper	50.0				50.0	33.0				33.0
	- Forward	58.0				58.0	39.0				39.0
1.1.5.1	Hatches - Upper	35.0				35.0	23.0				23.0
1.1.5.2	- Forward	35.0				35.0	23.0				23.0
1.1.6	Equip. Supports	94.0				94.0	73.0				73.0
1.1.7	Flooring	36.0				36.0	-				-
1.2	Insulation	50.0		22.0		72.0	33.0		22.0		55.0
1.3	Equipment Compartment	168.0				168.0	112.0				112.0
1.4	Bulkheads	(96.0)		(427.0)		(523.0)	(64.0)		(427.0)		(491.0)
1.4.1	Bulkhead - Ascent	96.0				96.0	64.0				64.0
1.4.2	- Descent - Upper			126.0		126.0			126.0		126.0
1.4.3	- Lower			75.0		75.0			75.0		75.0
1.4.4	- Tank			226.0		226.0			226.0		226.0
1.5	Engine/Tank Comp.	239.0		68.0		307.0	144.0		68.0		212.0

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LEM
DETAIL WEIGHT STATEMENT

CODE	ITEM	CURRENT WEIGHT					TARGET WEIGHT				
		BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
CONT.											
1.6	L.G. Skirt			(191.0)		(191.0)			(185.0)		(185.0)
1.6.1	L.G. Skin			133.0		133.0			133.0		133.0
1.6.2	L.G. Posts			40.0		40.0			34.0		34.0
1.6.3	L.G. Platform			18.0		18.0			18.0		18.0
1.7	Separation System			29.0		29.0			29.0		29.0

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M
DETAIL WEIGHT STATEMENT

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
2.0	Stabilization & Control	104.0		23.5		127.5 108	93.0		15.0		108.0
2.1	Guidance Coupler Ass'y	6.0				6.0	15.0				15.0
2.2	ATCA (Includes Power Supply)	15.0				15.0	15.0				15.0
2.3	Rate Gyro Ass'ys	13.0				13.0	6.0				6.0
2.4	In Flight Monitor	10.0				10.0	8.0				8.0
2.5	Descent Engine Control Ass'y			23.5		23.5			15.0		15.0
2.6	Back Up System	(60.0)				(60.0)	49.0				49.0
2.6.1	Computer	20.0				20.0					
2.6.2	Attitude Reference Assy.	40.0				40.0					

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LEM
DETAIL WEIGHT STATEMENT

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
3.0	Navigation & 158 Guidance	374.0		33.0		407.0 344 / 158	209.0		28.0		249.0
3.1	GFE (See note 1)	(328.0)				(328.0)	180.0				180.0
3.1.1	IMU	58.0				58.0					
3.1.2	SCT & Eyepieces	40.0				40.0					
3.1.3	AGC	108.0				108.0					
3.1.4	PSA	60.0				60.0					
3.1.5	NVB	20.0				20.0					
3.1.6	Cabling	40.0				40.0					
3.1.7	Star Maintenance Book	2.0				2.0					
3.2	Rendezvous Radar	(46.0)				(46.0)	41.0				41.0
3.2.1	Gimbled Ant.	10.0				10.0					
3.2.2	Electronics	26.0				26.0					
3.2.3	Transponder	10.0				10.0					
3.3	Landing Radar			(33.0)		(33.0)			28.0		28.0
3.3.1	3 Beam Stab Ant.			5.0		5.0					
3.3.2	Electronics			28.0		28.0					

Note 1: WTS per NASA LTR-SLM-63-128, May 20, 1963. 47# of Instr. are coded to Displays & Controls.

[redacted]

LEM
DETAIL WEIGHT STATEMENT

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
4.0	Crew Systems	580.0		15.6		596.4	552.0		16.0		568.0
4.1	Crew Accessories	(125.0)				(125.0)	(125.0)				(125.0)
4.1.1	Space Suits	60.0				60.0	60.0				60.0
4.1.2	Portable Life Support System	60.0				60.0	60.0				60.0
4.1.3	Radiation Dosimeter	5.0				5.0	5.0				5.0
4.2	Crew	353.2				353.2	353.2				353.2
4.3	Seats & Restraints	70.0				70.0	56.0				56.0
4.4	Lighting	(20.0)		(10.0)		(30.0)	(9.7)		(10.0)		(19.7)
4.4.1	Landing			10.0		10.0			10.0		10.0
4.4.2	Hatchway	4.0				4.0	.9				.9
4.4.3	Cabin	8.0				8.0	2.4				2.4
4.4.4	Running (docking)	8.0				8.0	6.4				6.4
4.5	Sustenance & Associated Equipment	(12.6)		(5.6)		(18.2)	(8.1)		(6.0)		(14.1)
4.5.1	Drinking Water					*					*
4.5.2	Food & Storage	10.1		5.6		15.7	8.1		6.0		14.1
4.5.6	First Aid Kit	2.5				2.5					0
4.6	Waste Management	-				-					-

[redacted]

LEM
DETAIL WEIGHT STATEMENT

CODE	ITEM	CURRENT WEIGHT					TARGET WEIGHT				
		BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
5.0	Environmental Control	290.9	85.2	126.4	21.0	523.5	186.4	61.6	137.5	30.0	415.5
5.1	Atmosphere Rev. Sect.	(88.7)		(26.4)		(115.1)	(68.5)		(7.5)		(76.0)
5.1.1	Suit Circuit Ass'y	30.8				30.8	22.0				22.0
5.1.2	Cabin Recirculation Ass'y	19.7				19.7	10.0				10.0
5.1.3	CO_2 Removal Cannister	3.3				3.3	2.0				2.0
5.1.4	Plumbing	18.4				18.4	29.7				29.7
5.1.5	LiOH Cartridges (13)*	16.5		26.4		42.9	4.8		7.5		12.3
5.2	Heat Transport Sect	(64.4)				(64.4)	(56.0)				(56.0)
5.2.1	Coolant Recirculation Ass'y	7.0				7.0	4.0				4.0
5.2.2	Valves and Switches	27.4				27.4	-				-
5.2.3	Cold Plates					**	28.0				28.0
5.2.4	Coolant	30.0				30.0	24.0				24.0
5.3	O_2 Supp. and Cabin Press. Sect. ***	(29.7)	(2.2)			(31.9)	(8.3)	(1.6)			(9.9)
5.3.1	Gox Accumulator	15.5				15.5	5.3				5.3
5.3.2	Gox	6.0	2.2			8.2	3.0	1.6			4.6
5.3.3	Valves and Switches	8.2				8.2	-				-
5.4	Water Management Sect	(88.1)	(83.0)	(100.0)	(21.0)	(292.1)	(33.7)	(60.0)	(130.0)	(30.0)	(253.7)
5.4.1	Water Tank	30.5				30.5	13.7				13.7
5.4.2	Water	55.0	83.0	100.0	21.0	259.0	20.0	60.0	130.0	30.0	240.0
5.4.3	Valves and Switches	2.6				2.6					
5.5	Plumbing GAEC	20.0				20.0	19.9				19.9

* Included are 4 PLSS replacement cartridges and 9 ECS cartridges
** Included in Structures
***Supercritical Oxygen And Tankage included under EPS.

LEM
DETAIL WEIGHT STATEMENT

CODE	ITEM	CURRENT WEIGHT: BURNOUT	CURRENT WEIGHT: CONS'D ON ASCENT	CURRENT WEIGHT: JET. ON LURAIN	CURRENT WEIGHT: CONS'D ON DESCENT	CURRENT WEIGHT: TOTAL SEP.	TARGET WEIGHT: BURNOUT	TARGET WEIGHT: CONS'D ON ASCENT	TARGET WEIGHT: JET. ON LURAIN	TARGET WEIGHT: CONS'D ON DESCENT	TARGET WEIGHT: TOTAL SEP.
6.0	Landing Gear			603.0		603.0			609.0		609.0
6.1	Upper Struts			80.0		80.0			80.0		80.0
6.2	Lower Struts			42.0		42.0			42.0		42.0
6.3	Shock Absorbers			64.0		64.0			64.0		64.0
6.4	Foot Pads & Ftgs			134.0		134.0			134.0		134.0
6.5	Mechanism			61.0		61.0			67.0		67.0
6.6	S IV B Attach. Penalty			39.0		39.0			39.0		39.0
6.7	L.G. Fittings			152.0		152.0			152.0		152.0
6.8	Mid Truss			31.0		31.0			31.0		31.0

LEM
DETAIL WEIGHT STATEMENT

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
7.0	Instrumentation	469.2		219.1		688.3	321.0		215.0		536.0
7.1	Operational Inst	(110.0)				(110.0)	(84.5)				(84.5)
7.1.1	Signal Conditioner	30.0				30.0	32.0				32.0
7.1.2	PCMTE	50.0				50.0	31.2				31.2
7.1.3	Data Storage Equip	30.0				30.0	21.3				21.3
7.2	IFTS	51.4				51.4	64.2				64.2
7.3	Scientific Equipt	80.0		170.0		250.0	80.0		170.0		250.0
7.4	Sensors*	(227.8)		(49.1)		(276.9)	92.3		45.0		137.3
7.4.1	Structure	25.5				25.5					
7.4.2	Stabilization and Control	28.2				28.2					
7.4.3	Navigation and Guidance	5.5				5.5					
7.4.5	ECS	27.8				27.8					
7.4.7	Instrumentation	3.3				3.3					
7.4.8	EPS	5.7				5.7					
7.4.9	Propulsion	60.5		49.1		109.6					
7.4.10	RCS	58.3				58.3					
7.4.11	Communications	13.0				13.0					

*Includes Operational and In-flight Test Systems

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LEM
DETAIL WEIGHT STATEMENT

CODE	ITEM	CURRENT WEIGHT BURNOUT	CURRENT WEIGHT CONS'D ON ASCENT	CURRENT WEIGHT JET. ON LURAIN	CURRENT WEIGHT CONS'D ON DESCENT	CURRENT WEIGHT TOTAL SEP.	TARGET WEIGHT BURNOUT	TARGET WEIGHT CONS'D ON ASCENT	TARGET WEIGHT JET. ON LURAIN	TARGET WEIGHT CONS'D ON DESCENT	TARGET WEIGHT TOTAL SEP.
8.0	Electrical Pwr Supply	659.2	17.3	138.7	7.5	822.7	419.4	18.6	55.1	44.4	537.5
8.1	Power Generation	(336.2)	(17.3)	(120.7)	(7.5)	(481.7)	(219.4)	(18.6)	(42.1)	(44.4)	(324.5)
8.1.1	Fuel Cells (3) *	157.8				157.8	112.3				112.3
8.1.2	Oxygen Tanks (2)	3.6		14.2		17.8	27.3		16.9		44.2
8.1.3	Hydrogen Tanks (3)	20.0		33.5		53.5	53.0				53.0
8.1.4.1	Oxygen - Ascent **	7.6	10.9			18.5		13.8			13.8
8.1.4.2	- Descent **			61.0	4.8	65.8			25.2	35.4	60.6
8.1.5.1	Hydrogen - Ascent	.6	6.4			7.0		4.8			4.8
8.1.5.2	- Descent			12.0	2.7	14.7				9.0	9.0
8.1.6	Peaking Battery System	17.0				17.0	17.0				17.0
8.1.7	Pressure Regulators	3.2				3.2	2.6				2.6
8.1.8	Fuel Cell Control Units (3)	52.2				52.2	2.4				2.4
8.1.9	Plumbing	57.2				57.2					
8.1.10	Pyrotechnic Battery (2)	10.0				10.0					
8.1.11	Battery Charger (1)	5.0				5.0	4.0				4.0
8.1.12	Heat Exchanger	2.0				2.0	.8				.8
8.2	Power Conversion Sect.										
8.2.1	Inverters (2)	60.0				60.0	48.0				48.0
8.3	Distribution Sect.	(81.0)				(81.0)	(49.0)				(49.0)
8.3.1	Distribution Boxes (2)	30.0				30.0	8.0				8.0
8.3.2	Circuit Breaker Panels (2)	16.0				16.0	13.0				13.0
8.3.3	Junction Boxes (2)	15.0				15.0	12.0				12.0
8.3.4	Relay Boxes (2)	20.0				20.0	16.0				16.0
8.4	Electrical Provisions	182.0		18.0		200.0	103.0		13.0		116.0

* Target weight is for two fuel cells
** Includes ECS supercritical oxygen and tankage.

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LEM
DETAIL WEIGHT STATEMENT

CODE	ITEM	CURRENT WEIGHT BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D. ON DESCENT	TOTAL SEP.	TARGET WEIGHT BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
9.0	Propulsion System	561.4	4329.0	1592.6	15474.0	21957.0	516.0	3837.0	1806.0	13994.0	20153.0
9.1	Propellant	(46.0)	(4329.0)	(163.0)	(15474.0)	(20012.0)	(46.0)	(3837.0)	(163.0)	(13994.0)	(18040.0)
9.1.1.1	Usable - Ascent		4329.0			4329.0		3837.0			3837.0
9.1.1.2	- Descent				15474.0	15474.0				13994.0	13994.0
9.1.2.1	Trapped - Ascent	46.0				46.0	46.0				46.0
9.1.2.2	- Descent			163.0		163.0			163.0		163.0
9.2	Propellant System	(209.6)		(540.3)		(749.9)	(197.0)		(620.0)		(817.0)
9.2.1	Fuel Tanks - Ascent	80.0				80.0	76.0				76.0
9.2.2	- Descent			242.0		242.0			218.0		218.0
9.2.3	Oxidizer Tanks										
	- Ascent	80.0				80.0	76.0				76.0
9.2.4	- Descent			242.0		242.0			218.0		218.0
9.2.5	Plumbing - Ascent	49.6				49.6	45.0				45.0
9.2.6	- Descent			56.3		56.3			184.0		184.0
9.3	Pressurization System	(131.8)		(473.2)		(605.0)	(130.0)		(599.0)		(729.0)
9.3.1	Helium Tanks - Ascent	90.0				90.0	90.0				90.0
9.3.2	- Descent			393.0		393.0			454.0		454.0
9.3.3	Helium - Ascent	11.0				11.0	11.0				11.0
9.3.4	- Descent			42.0		42.0			64.0		64.0
9.3.5	Plumbing - Ascent	30.8				30.8	29.0				29.0
9.3.6	- Descent			38.2		38.2			81.0		81.0
9.4	Engines	(174.0)		(416.1)		(590.1)	(143.0)		(424.0)		(567.0)
9.4.1	Engine - Ascent (Bell)	131.0				131.0	110.0				110.0
9.4.2	- Descent (Rocketdync)			358.5		358.5			350.0		350.0
9.4.3	Shield	30.0		14.6		44.6	20.0		20.0		40.0
9.4.4	Gimbal Actuators			14.0		14.0			25.0		25.0
9.4.5	Mount	5.0		8.0		13.0	5.0		8.0		13.0
9.4.6	Misc.	8.0		21.0		29.0	8.0		21.0		29.0

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LEM
DETAIL WEIGHT STATEMENT

CODE	ITEM	CURRENT WEIGHT BURNOUT	CURRENT WEIGHT CONS'D ON ASCENT	CURRENT WEIGHT JET. ON LURAIN	CURRENT WEIGHT CONS'D ON DESCENT	CURRENT WEIGHT TOTAL SEP.	TARGET WEIGHT BURNOUT	TARGET WEIGHT CONS'D ON ASCENT	TARGET WEIGHT JET. ON LURAIN	TARGET WEIGHT CONS'D ON DESCENT	TARGET WEIGHT TOTAL SEP.
10.0	RCS	313.6	405.0	—	71.0	789.6	160.2	232.0	—	51.0	443.2
10.1	Propellant	0	(405.0)	-	(71.0)	(490.0)	0	(232.0)	-	(51.0)	(283.0)
	Attitude CTL	0	198.0	-	54.0	252.0	0	89.0	-	34.0	123.0
	For Δ V	0	207.0	-	17.0	224.0	0	143.0	-	17.0	160.0
10.1.2	Trapped	14.0	-	-	-	14.0	0	0	-	0	0
10.2.1	Fuel Tanks	16.8	-	-	-	16.8	8.0				8.0
10.2.2	Oxid. Tanks	16.8	-	-	-	16.8	8.0				8.0
10.2.3	Tank Plumbing	(77.4)	-	-	-	(77.4)	(25.0)				(25.0)
	Ascent Tie In	7.0	-	-	-	7.0	2.4				2.4
	Fuel System	23.2	-	-	-	23.2	5.5				5.5
	Ox System	23.2	-	-	-	23.2	5.5				5.5
	Thruster ISL Valve	24.0	-	-	-	24.0	11.6				11.6
10.3	Pressurization	(44.0)	-	-	-	(44.0)	(23.2)				(23.2)
10.3.1	He Tank	10.2	-	-	-	10.2	8.0				8.0
10.3.2	He Gas	1.4	-	-	-	1.4	.8				.8
10.3.3	Plumbing	32.4	-	-	-	32.4	14.4				14.4
10.4	Thruster Instl Assy	(104.6)	-	-	-	(104.6)	(64.0)				(64.0)
	Thrusters	70.2	-	-	-	70.2	64.0				64.0
	Cluster Hdwre	26.4	-	-	-	26.4	0				0
	TCA Failure Device	8.0	-	-	-	8.0	0				0
10.5	Quad Support Truss	40.0	-	-	-	40.0	32.0				32.0

LEM
DETAIL WEIGHT STATEMENT

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
11.0	Communications	79.4		21.5		100.9	38.0		61.0		99.0
11.1	Intercom (Audio Center)	5.0				5.0	4.8				4.8
11.2	VHF LEM/CM	(14.4)				(14.4)	(18.4)				(18.4)
11.2.1	VHF Transciever	4.4				4.4	9.9				9.9
11.2.2	" OMNI Ant.	1.5				1.5	1.6				1.6
11.2.3	" Diplexer	2.5				2.5	2.0				2.0
11.2.4	" Lunar Stay Ant	5.0				5.0	4.0				4.0
11.2.6	" R.F. Switch	1.0				1.0	.9				.9
11.3	Premod. Processor	10.0				10.0	14.8				14.8
11.4	UHF LEM/Earth	(50.0)		(10.0)		(60.0)			(61.0)		(61.0)
11.4.1	" Transponder	15.0				15.0			17.0		17.0
11.4.2	" Power Amp	11.0				11.0			8.5		8.5
	" Diplexer	1.0				1.0			1.0		1.0
11.4.3	" Fixed Ant	1.0				1.0			3.0		3.0
11.4.4	" Erectable Ant	-		10.0		10.0			10.0		10.0
11.4.5	" Steerable Dish	8.0				8.0			8.0		8.0
	" Earth Sensor & Dr.	12.0				12.0			12.0		12.0
11.4.6	" R.F. Switch	1.0				1.0			1.0		1.0
11.4.7	" & VHF Pwr Dividers	1.0				1.0			.5		.5
11.5	Television			(11.5)		(11.5)					-
11.5.1	Camera, Portable			5.5		5.5					
11.5.2	Lens			2.5		2.5					
11.5.3	Cable & Reel			2.5		2.5					
11.5.4	Aux. Light			1.0		1.0					

LEM
DETAIL WEIGHT STATEMENT

CODE	ITEM	CURRENT WEIGHT BURNOUT	CURRENT WEIGHT CONS'D ON ASCENT	CURRENT WEIGHT JET. ON LURAIN	CURRENT WEIGHT CONS'D ON DESCENT	CURRENT WEIGHT TOTAL SEP.	TARGET WEIGHT BURNOUT	TARGET WEIGHT CONS'D ON ASCENT	TARGET WEIGHT JET. ON LURAIN	TARGET WEIGHT CONS'D ON DESCENT	TARGET WEIGHT TOTAL SEP.
12.0	Display & Controls	238.1				238.1	198.0				198.0
12.1	Structure										
12.2	Stabilization & Control	69.9				69.9	55.3				55.3
12.3	Nav. & Guidance	62.0				62.0	59.6				59.6
12.4	Crew Systems										
12.5	Environmental Control	12.2				12.2	9.8				9.8
12.6	Lunar Landing System	2.0				2.0	1.6				1.6
12.7	Instrumentation										
12.8	Electrical Power Supply	20.0				20.0	16.0				16.0
12.9	Propulsion	10.0				10.0	8.0				8.0
12.10	Reaction Control	7.9				7.9	6.3				6.3
12.11	Communications	10.1				10.1	8.1				8.1
12.12	Instrument Panel & Side Consoles	44.0				44.0	33.3				33.3

LEM
DETAIL WEIGHT STATEMENT

		CURRENT WEIGHT					TARGET WEIGHT				
CODE	ITEM	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.	BURNOUT	CONS'D ON ASCENT	JET. ON LURAIN	CONS'D ON DESCENT	TOTAL SEP.
13.0	Spares	41.0				41.0 -	41.0				41.0
13.1	Structure										
13.2	Stabilization and Control										
13.3	Navigation and Guidance										
13.4	Crew System										
13.5	Environmental Control										
13.6	Lunar Landing Sys.										
13.7	Instrumentation	8.5				8.5					
13.8	Electrical Power System										
13.9	Main Propulsion										
13.10	Reaction Control										
13.11	Communications										
13.12	Displays and Controls										
13.13	Unallocated	32.5				32.5	41.0				41.0

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APPENDIX A

LEM GROWTH FACTOR

INTRODUCTION

The growth factor is a convenient tool used to simplify evaluations of subsystem configurations and vehicle sizing. It eliminates the cumbersome calculations involved in handling subsystems, which are vehicle weight and size sensitive. Subsystems whose weights are determined by the mission (i.e. Electronics, Environmental Control, and other similar subsystems) are independent of the vehicle size and weight and are easily handled. The problem arises in evaluating subsystems whose weights vary with vehicle size and weight (i.e. Landing Gear, Structure, Propulsion and Pressurization Subsystems). The solution to the problem lies in treating these subsystems as variables and making certain assumptions and approximations.

Assumptions were made for parameters that affected Engine, Pressurization and Propellant Tank subsystems, Landing Gear and Structures. Expansion ratio, chamber pressure and ablative vs. regeneratively cooled nozzles were considered for the engines; materials, bladder vs. baffles, and number of tanks were considered for the Propellant Tank and Pressurization Subsystems; in the case of the Structure and Landing Gear, the level of meteoroid shielding, method of suspension in the booster adapter, number of landing gear, and retractable vs. fixed landing gear were considered. These subsystems were handled as variables, they were equated to propellant weight and plotted as a function of subsystem weight vs. propellant weight (See Figure III and IV). The values used were approximations which were later verified with the latest available information. The growth factor, includes the weight of propellant to lift a known weight (or mass ratio) plus an increment that includes the subsystems that vary with vehicle size and weight. Consequently, the use of growth factor defines a rubberized vehicle. The relationship between growth factor and mass ratio is proportional to the number of subsystems which are sensitive to size and weight. The greater the number of subsystems sensitive to vehicle weight and size, the greater is the difference between the growth factor and mass ratio. As the subsystems become frozen, the growth factor will approach and equal the mass ratio. As is seen from Figure II, the descent stage growth factor has a larger slope than the ascent stage because more descent stage items are weight and size dependent than in the ascent stage.

In conclusion, the growth factor provides a simplified method for vehicle sizing studies. In studies of constant weight subsystems the growth factor provides a way of determining the effect on the total vehicle that a system has, and it defines the weight saving associated with staging or integrating subsystems in terms of effective weight or LEM weight at separation.

In making weight comparisons of LEM configurations the use of Growth Factors afford a simplified method of calculating the Wet and Dry Vehicle Weights. In addition, by using the curves of stage weight vs. propellant WT, the weight of the subsystems can be broken out.

The following is the derivation of Growth Factor:

1) $\Delta V = g \ I_s \times \ln W_o/W_f$

2) If $K = \dfrac{\Delta V}{g \ I_s}$

I_s = Specific Impulse

W_o = Initial Weight

W_f = Final Weight

3) Then $e^K = W_o/W_f$ = Mass Ratio

The difference between W_o and W_f is only the propellant. Food and other expendables will be treated separately.

4) $W_p = W_o - W_f$

From (3) above $W_o = W_f \times e^K$

5) $W_p = W_f \ e^K - W_f$

6) $W_p = W_f \ (e^K - 1)$

Equation (6) gives the weight of propellant required to carry a specific final weight. If any additional weight is added to the vehicle the propellant required can be found from EQ (6), however, no allowance is made for tankage to carry the additional propellant, or propellant to carry the larger tanks, or the weight of other systems that grow in proportion to the propulsion. The Growth Factor is the weight effect that each pound has on the total vehicle in terms of propellant, and an increment that includes the inert systems that vary with the propulsion system.

Expressing the above statement mathematically and reducing the payload to unity to give a factor it becomes:

7) Growth Factor = $(W + W_p + W_I + W_{P_I} + W_{I_1} + W_{P_{I_1}} + W_{I_2})$ .....

Substituting EQ (6) for W_p

$$\text{Growth Factor} = W + W\,(e^K - 1) + W_I + W_I\,(e^K - 1) + W_{I_1} + W_{I_1}\,(e^K - 1) \ldots\ldots$$

8) $$\text{Growth Factor} = e^K\,(W + W_I + W_{I_1} + W_{I_2} \ldots\ldots)$$

The inert systems weight (W_I) is obtained from curves (Fig. III & IV) based on calculations made by GAEC. The curves show the various subsystems that make up the Inert weight vs weight of propellant.

From EQ (2) & (3) it is seen the Mass Ratio is a function of ΔV and I_s. Fig. I is a plot of Mass Ratio vs ΔV for various I_s. Fig. II is a plot of Mass Ratio vs Growth Factor for the inert subsystem increments referenced above. Based on the 1 May 1963 ΔV Budget the following Mass Ratios and Growth Factors were obtained from Fig. I & II.

	Descent	Ascent
ΔV =	7827 FPS	7079 FPS
I_s =	305 Sec	303 Sec
MR =	2.22	2.068
GF =	2.824	2.366

Verification of Mass Ratio and Growth Factor for Descent

ΔV = 7827 FPS
I_s = 305 Sec

$$K = \frac{\Delta V}{g\,I_s} = \frac{7827}{32.2 \times 305} \qquad \text{(EQ 2)}$$

$$K = .797$$

$$e^K = \text{Mass Ratio} = e^{.797} \qquad \text{(EQ 3)}$$

$$e^{.797} = 2.220$$

$$\text{Growth Factor} = e^K\,(W + W_I + W_{I_1} + W_{I_2} \ldots\ldots) \qquad \text{(EQ 8)}$$

$W = 1$ LB

W_I = WT of inert subsystem due to increase in propellant to carry W.

$$W_I = \left[W\,(e^K - 1) \right] \times .1762$$

$$W_I = .215$$

W_{I_1} = WT of inert subsystem due to increase in propellant to carry W_I.

$$W_{I_1} = \left[.215\,(e^K - 1) \right] \times .1762 \qquad W_{I_2} = \left[.046\,(e^K - 1) \right] \times .1762$$

$$W_{I_1} = .046$$

Growth Factor = 2.22 (1 + .215 + .046 + .0099)
Growth Factor = 2.824

Verification of Mass Ratio and Growth Factor for Ascent

ΔV = 7079 FPS
I_s = 303 Sec

$$K = \frac{\Delta V}{g\,I_s} = \frac{7079}{32.2 \times 303} \qquad \text{(EQ 2)}$$

$$K = .726$$

$$e^K = \text{Mass Ratio} = e^{.726} \qquad \text{(EQ 3)}$$

$$e^K = 2.068$$

$$\text{Growth Factor} = e^K\,(W + W_I + W_{I_1} \; .....) \qquad \text{(EQ 8)}$$

$W = 1$ lb

W_I = WT of inert subsystem due to increase in propellant to carry W

$$W_I = \left[W\,(e^K - 1) \right] \times .1188$$

$$W_I = .1269$$

W_{I_1} = WT of inert subsystem due to increase in propellant to carry W_I.

$$W_{I_1} = \left[.1269\,(e^K - 1) \right] \times .1188 \qquad W_{I_2} = \left[.0151\,(e^K - 1) \right] \text{X } .1188$$

$W_{I_1} = .0151$ $\qquad\qquad$ $W_{I_2} = .0019$

Growth Factor = 2.068 (1 + .1269 + .0151 + .0019)

Growth Factor = 2.366

The round trip Growth Factor is the affect one pound has on the vehicle when carried from separation to burnout and is the product of the Ascent and Descent Growth Factors.

Round Trip Growth Factor = 2.824 x 2.366

= 6.682

In working with Growth Factors the following basic facts must be remembered:

1. The Ascent and Descent Growth Factors are obtained by using the appropriate ΔV and I_s for that particular mission phase.

2. The Round Trip (unstaged) Growth Factor is the product of the Ascent and Descent Growth Factors.

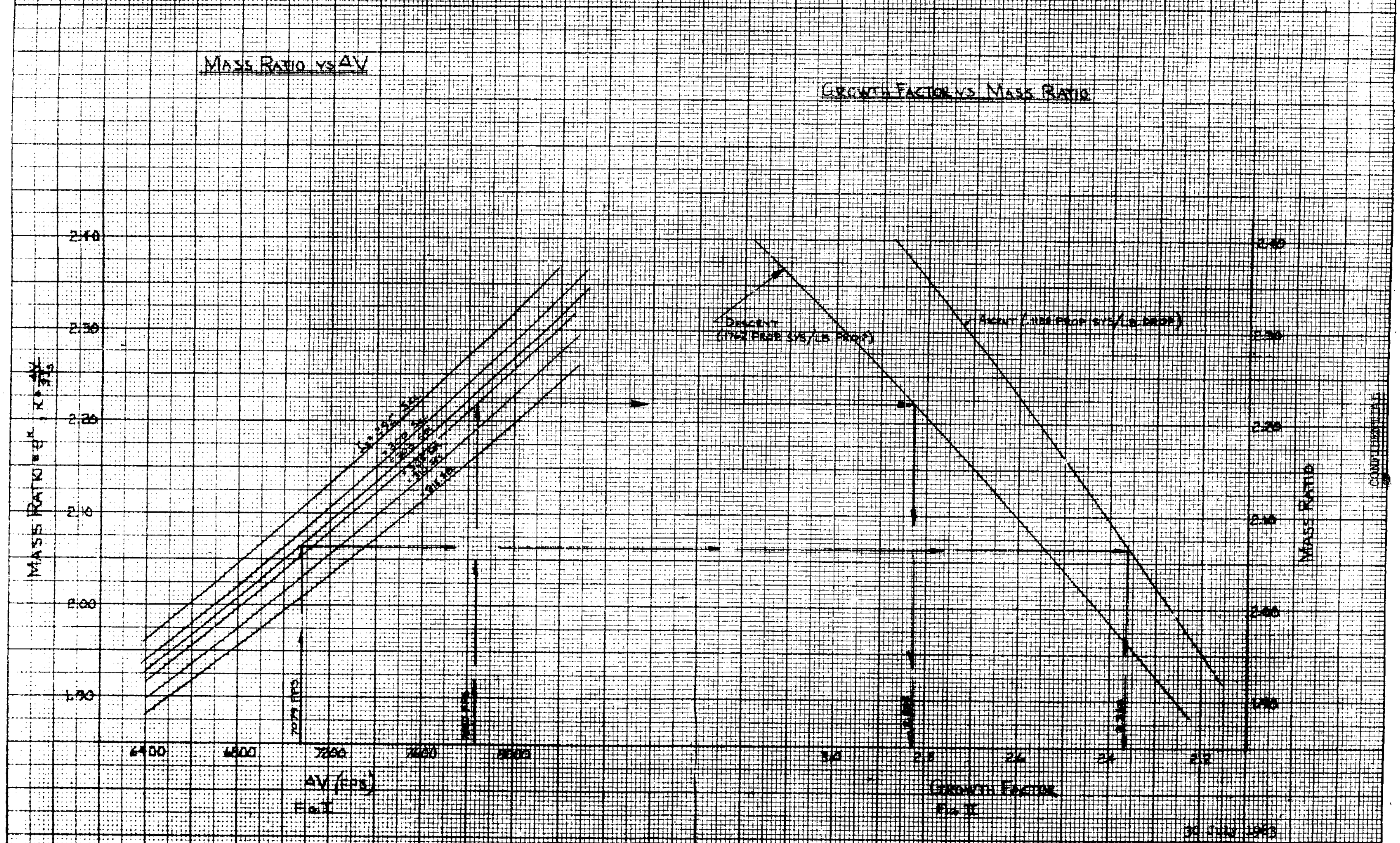
3. All items carried from separation to touchdown (staged) must be multiplied by the Descent Growth Factor 2.824.

4. All items carried from Separation to Burnout (unstaged) must be multiplied by the Round Trip Growth Factor 6.682.

5. To obtain the affect of items carried from lift-off to Burnout in the Ascent Stage multiply the item by the Ascent Growth Factor 2.366.

6. The penalty for lunar lift off capability differs from the Round Trip Growth Factor. The lunar lift-off payload is only carried from the lunar surface to burnout, however, the Descent stage must carry an increase in propellant to land the Ascent stage propellant required to carry the lunar payload. The lunar lift-off capability factor is 4.285.

[redacted]



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INERT ASCENT PROPULSION SYSTEM WEIGHT
VS
PROPELLENT WEIGHT

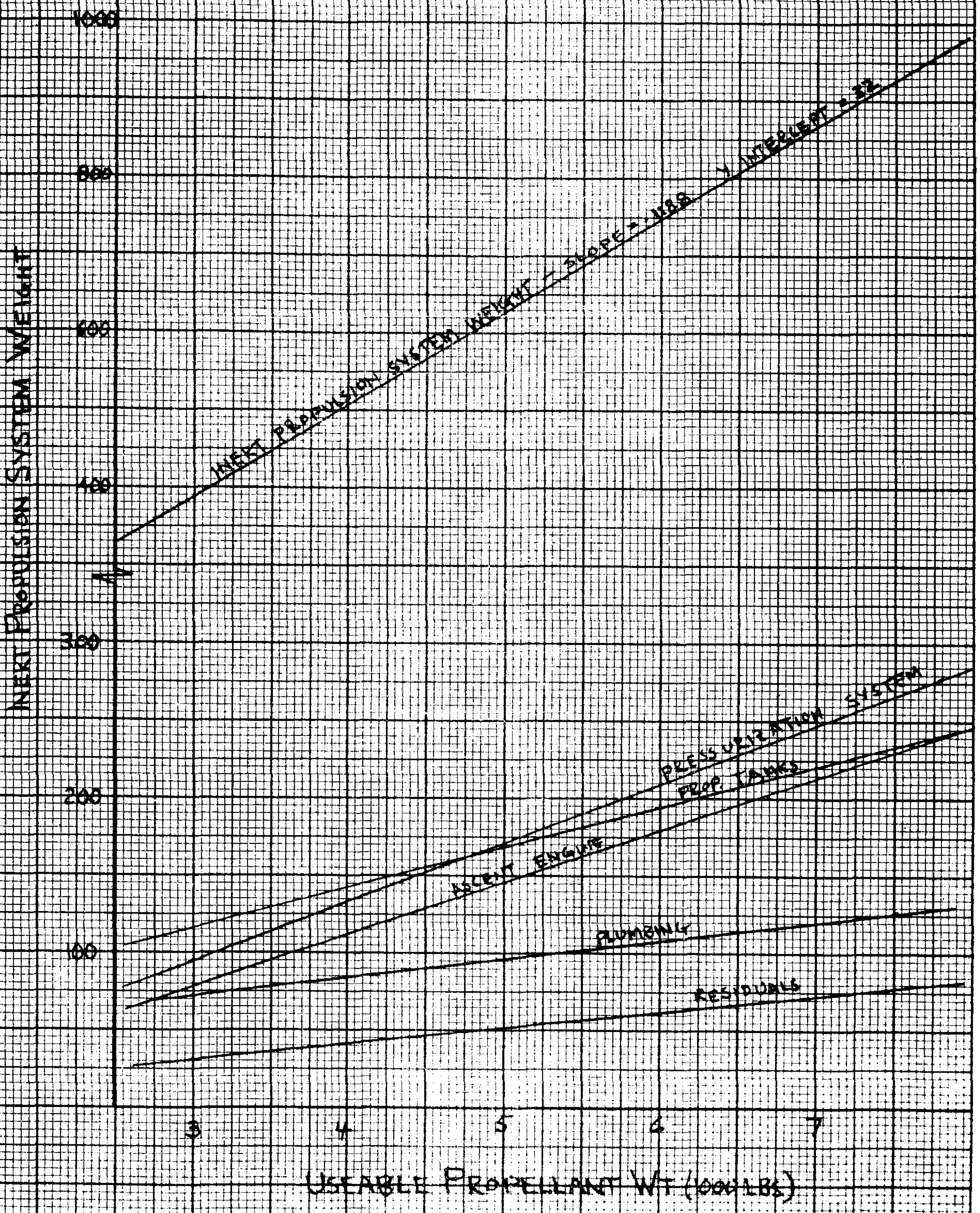

FIG III

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DESCENT STAGE WEIGHT VS PROPELLANT WEIGHT

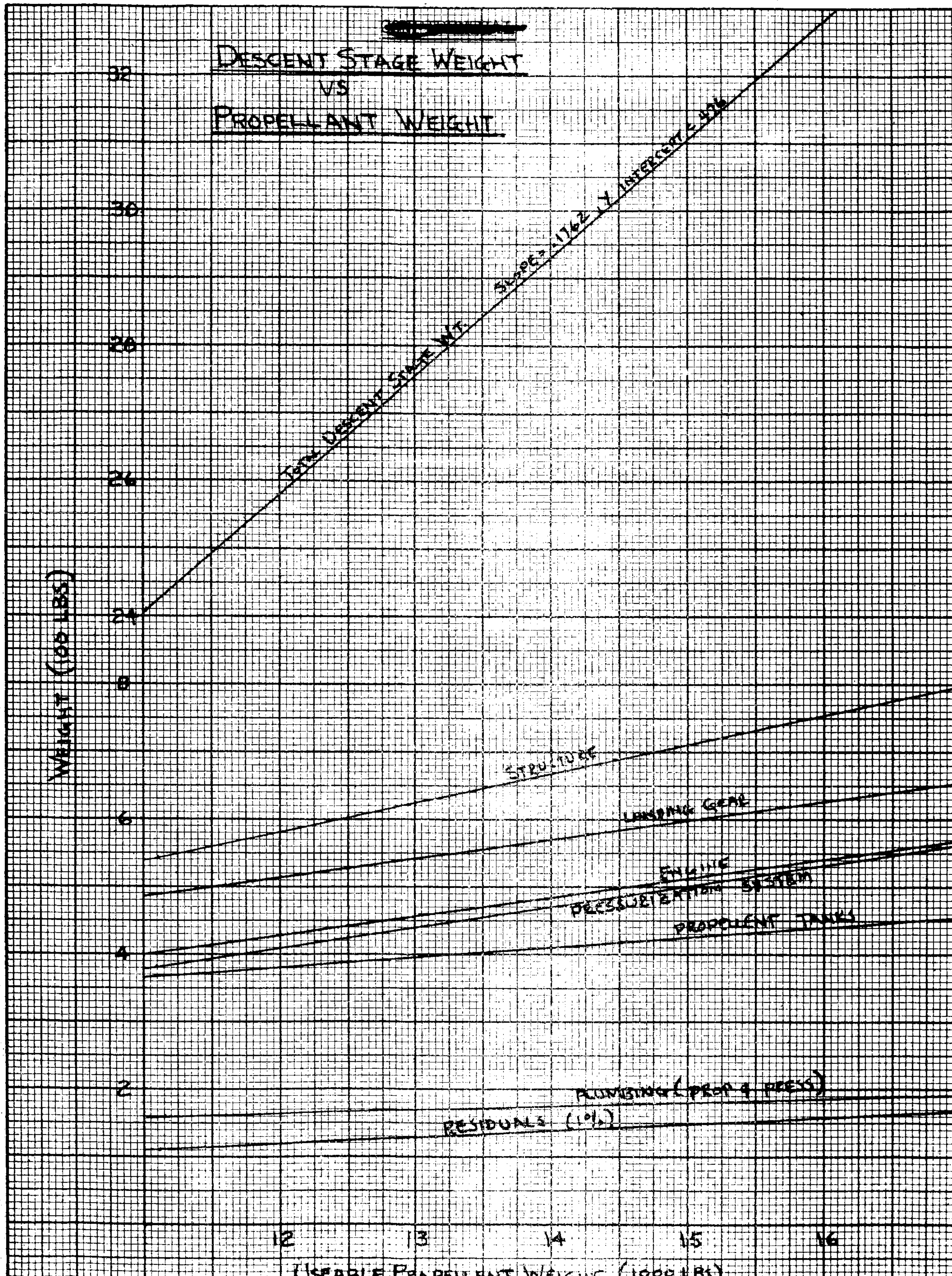

FIG IV

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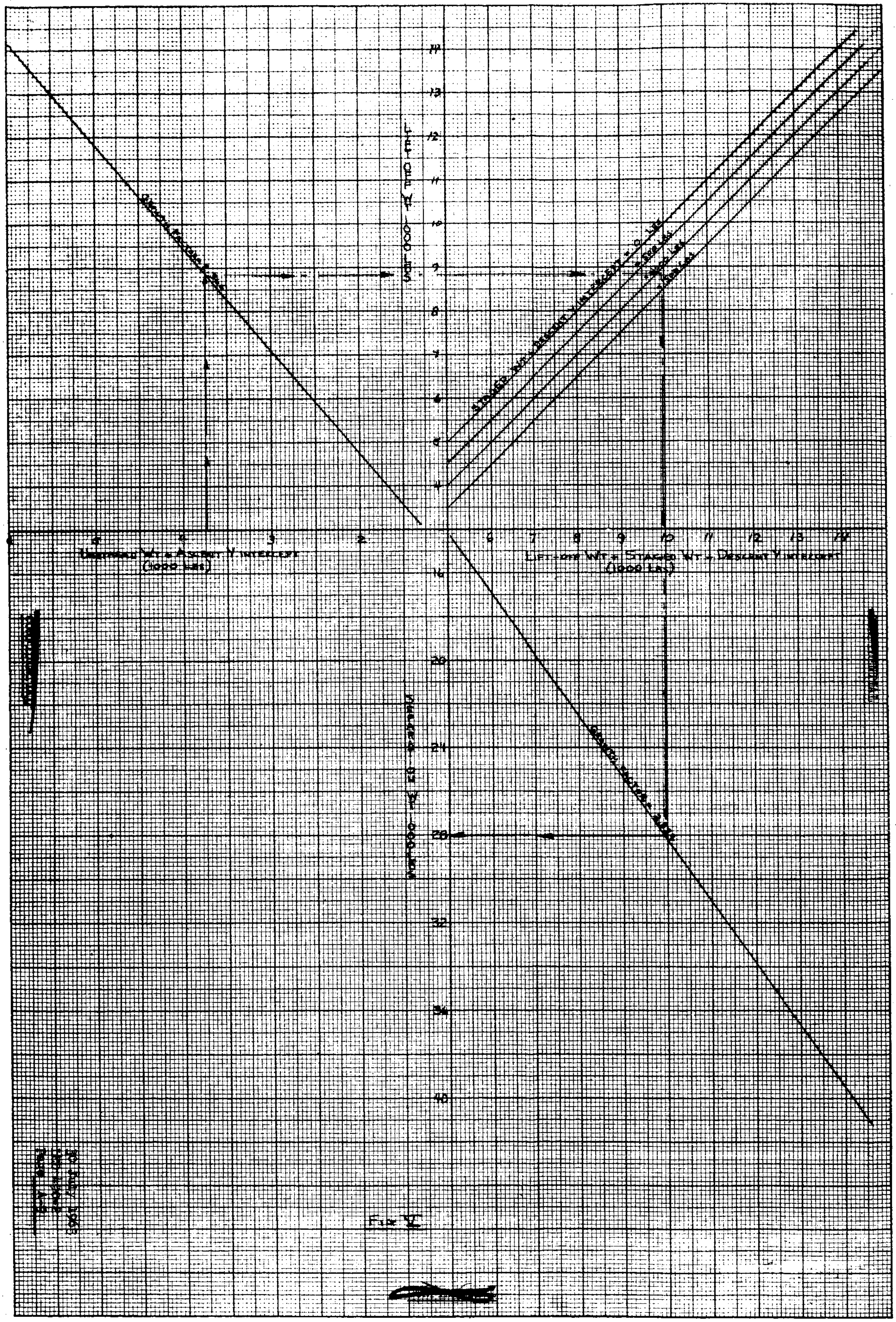
Lift-off Wt - 1000 lbs
Lift-off Wt = Staged Wt + Descent V intercept
(1000 lbs)
(1000 lbs)

Fig V

APPENDIX B

PROPELLANT TANK SIZING AND CRITERIA

Design Conditions:

	Descent	Ascent
I_{sp} Specific Impulse	302 seconds	306 seconds
ΔV MAIN ENGINE	7822 fps	6628 fps
ΔV RCS	5 fps	451 fps
ΔV STAGE	7827 fps	7079 fps
(W_o) Initial Stage Weight	28000#	8837#

Specific Impulse (Isp)

The Isp(s) used for tank sizing are based on the curves, figures 1, 3 and 4 attached, of Ref. no. 3. The ascent specific impulse was rounded down to 306.0 which represents a slight conservatism over the Grumman nominal of Figure 1. This was done because of the large disparity between the Grumman estimate of the ascent engine specific impulse envelope and the engine manufacturer's estimated specific impulse envelope. The descent specific impulse is a time integrated average based on Figure 3 (Isp vs. Thrust) and the thrust vs. time called for by Ref. 6. This thrust program calls for a burning at constant thrust for 238 seconds; the initial thrust/weight ratio = .396. At 28000 lb. initial weight the thrust called for would be 11088 lbs. so for this portion of the trajectory it is assumed that the engine is thrusting at the maximum nominal value of 10500 lbs. The final phase of the descent calls for thrust at 10500 lbs. for 20 seconds, thrust decay to 5200 lb. over the next 90 seconds and then thrust dropping to 2400 lbs. over the next 33 seconds at which time touch-down has been accomplished. The combined effect of the above yields an average Isp of 302 seconds.

Delta Velocity

The 10% reserve allotted to cover the positive uncertainties as outlined in Ref. no. 4 was divided proportionally between the main engine and reaction control system and is included in the ΔV's listed above.

Useable Propellant - Calculation of

$$\frac{W_o}{W_f} = e^K \qquad \text{where:} \quad K = \frac{\Delta V}{I_{sp}\,(g)}$$

For the descent phase 17 lbs. of R.C.S. propellant weight was removed from the 28000 lbs. to give a corrected initial weight (Wo) of 27983 lbs. This was done because the R.C.S. propellant is used to separate the LEM from the CM/SM. Therefore, the main engine propellant has to impart the 7822 fps Δ V to a vehicle weighing 27983 lbs. Since the main engine fires first during ascent phase no such adjustment had to be made to the ascent stage initial weight of 8837 lbs.

Trapped And Useable Propellant

Useable Propellant Weight		15474#	4329#
Trapped in System	1/2%	78	22
Trapped in Engine		17	8
Loading Tolerance	1/2%	78	22
Off O/F Ratio	1%	155	43
		(328)	(95)

Propellant weights for which tank volume must be provided.

	Descent 15,802		Ascent 4,424	
	OX	FUEL	OX	FUEL
at O/F = 1.60	9724	6078	2722	1702
Densities at lbs./ft^3 65°F (1)	90.45	56.49	90.45	56.49
Densities at lbs./ft^3 90°F (1)	88.49	55.69	88.49	55.69
Volume at 65°F (ft^3)	107.5	107.6	30.09	30.13

(1) Reference No. 7

Ullage Volume Derivation:

Conditions

p_1 is the fueling back pressure

p_2 is the design maximum gas pressure in the ullage volume after the tanks are heated to t_{max} (90°F) from minimum fueling temperature of t_1.

	OX	FUEL	OX	FUEL
p_1 psia	20	20	20	20
p_2 psia	120	120	100	100
t_1 °F	65	65	65	65
t_2 °F	90	90	90	90
Percentage of Liquid Volume at 65°F needed for Ullage	2.68	1.74	2.80	1.82
Critical Tank Volumes	95,386 in.^{3}*		26,732 in.^{3}*	
Allowance for Internal Equip.	250		178	

Allowance for Tank Expansion: Assumed negligible as tank is only pressurized to p_2 above and the effect of tank distortion under pressure is not known at this time.

Effect of Pressure on Liquid Densities - Negligible

Design Tank Vols. Each of (4)	95,636 in.^{3} 55.34 ft.^{3}	26,910 in.^{3} 15.57 ft.^{3}

* Since the oxidizer has a higher thermal co-efficient of expansion, and identical oxidizer and fuel tanks are desired, the oxidizer volume requirements become critical for sizing both the fuel and oxidizer tanks. This is noted by the higher ullage requirements for the oxidizer.

The fueling conditions are specified as entering liquids at 70°F ±5F°; therefore, the most dense liquids will be loaded at 65°F which point has been taken as the base from which to calculate the ullage volume.

The maximum temperature the liquids will reach is 90°F and the fueling will take place with a back pressure of 20 psia in the tanks. It was decided to allow the pressure to rise to 100 psia in the ascent tanks and 120 psia in the descent tanks. It is felt these pressures are sufficiently below the burst disc and relief valve pressures to negate any problem in this area. It was assumed that as the liquids expanded to 90°F the gas in the ullage volume maintained the same temperature and did not contain any propellant vapors. The latter assumption is slightly conservative with respect to the actual final pressure that will occur at t_{max}. To meet these conditions the general gas equation dictates that the descent oxidizer and fuel tanks have 2.68 and 1.74 percent of their 65°F volume for ullage respectively and the ascent tanks have 2.80% and 1.82% respectively.

Sample ullage volume calculation ascent stage oxidizer.

Conditions p_1 = 20 psia t_1 = 65°F

p_2 = 100 psia t_2 = 90°F

V_1 = volume of oxidizer at 65°F

V_2 = volume of oxidizer at 90°F

v_1 = volume of ullage gas at 65°F and 20 psia

v_2 = volume of ullage gas at 90°F and 100 psia

(1) $V_1 + v_1 = V_2 + v_2$

$$\frac{2722\#}{90.45} + v_1 = \frac{2722\#}{88.49} + v_2$$

$$30.09 + v_1 = 30.76 + v_2$$

$$V_1 - V_2 = .67 \text{ ft}^3$$

(2) $$\frac{v_1}{v_2} = \frac{\dfrac{WR\ 525\ ^\circ R}{20\ (144)}}{\dfrac{WR\ 550\ ^\circ R}{100\ (144)}} = 4.773$$

So $v_2 = \dfrac{v_1}{4.773}$

Substituting (2) - (1) gives:

$$v_1 - \frac{v_1}{4.773} = .67 \text{ ft.}^3$$

$$v_1 = .847 \text{ ft.}^3$$

or $\dfrac{v_1}{V_1} = \dfrac{.847}{30.09} = .028$ = 2.8% of the oxidizer volume at 65°F (525 °R)

Since the volumes of oxidizer and fuels are very nearly equal at the weight O/F ratio of 1.6 to 1.0 it is possible to make the tanks identical, a very economically desirable feature. To do this the tanks must allow for the maximum required volume and be slightly oversized for the other liquid. The critical volumes are those for the oxidizer in each stage.

These volumes are:

95,386 cubic inches in each descent stage tank.
26,732 " " " " ascent " "

To these volumes, allowances of 250 cu. in. descent and 178 cu. in. ascent for internal equipments in each tank were added. Therefore, the minimum tank volumes for each of four tanks per stage are:

95,636 cubic inches - descent
26,910 cubic inches - ascent

For the above volumes the minimum tank propellant tank dimensions are:

Ascent: Spherical tanks (4) of $I.D._{min}$ = 37.18"; all manufacturing tolerances are to be such that the tanks at 65°F do not have a diameter below this value.

Descent: Cylindrical mid section of 51" I.D. and a 12.81" minimum length between spherical (51.00" I.D.) end bells. The same tolerance criteria as above apply.

Other factors involved in tank design but with effects considered negligible for purposes of sizing the tanks (i.e. determining the tank volumes) are:

1. Allowance for tank expansion between p_1 and p_2.

2. Effect of pressure on liquid densities.

Since the increase in tank pressure during liquid warm up is only 80 or 100 psi and effect of tank distortion is not known at this time, (1) above was neglected.

Definitions and Symbols

I_{sp} Rocket motor specific impulse;

$$I_{sp} = \frac{\int_{o}^{t_b} T\,dt}{Wp}$$ where: t_b = time of engine burnout

$$I_{sp} = \frac{T}{Wp}$$ T = Engine Thrust

Wp = Weight of propellants burned.

ΔV The net change in vehicle velocity for the phase of operation under discussion. Also the vector sum of all the time integrated accelerations that have acted on the vehicle for the time under consideration.

W_O The initial weight of the vehicle for the period under consideration.

W_F The weight of the vehicle at the end of the particular phase.

W_p The weight of propellant necessary to produce a certain ΔV; also equals $W_O - W_F$.

K $\dfrac{\Delta V}{I_{sp}(g)}$ Where g is the constant for changing weight to mass g = 32.1739.

REFERENCE FOR APPENDIX B

1. GAEC LMO-490-8 (15 June 1963) "LEM Target Weights"

2. GAEC LMO-490-10 (24 June 1963) "LEM--- Tank Sizes and Criteria ------"

3. GAEC LMO-271-5 (23 July 1963) Preliminary Estimates of Ascent and Descent Performance Tolerances

4. GAEC LMO-500-37A (8 May 1963) "LEM ΔV Budget-------"

5. GAEC LMO-500-43 (7 May 1963) "Trip Report --------- ΔV Budget Meeting -------"

6. GAEC LMO-500-48 (22 May 1963) "Trajectory Characteristics During the LEM Mission, II"

7. Areojet - General Report No. LRP - 198 Second Edition

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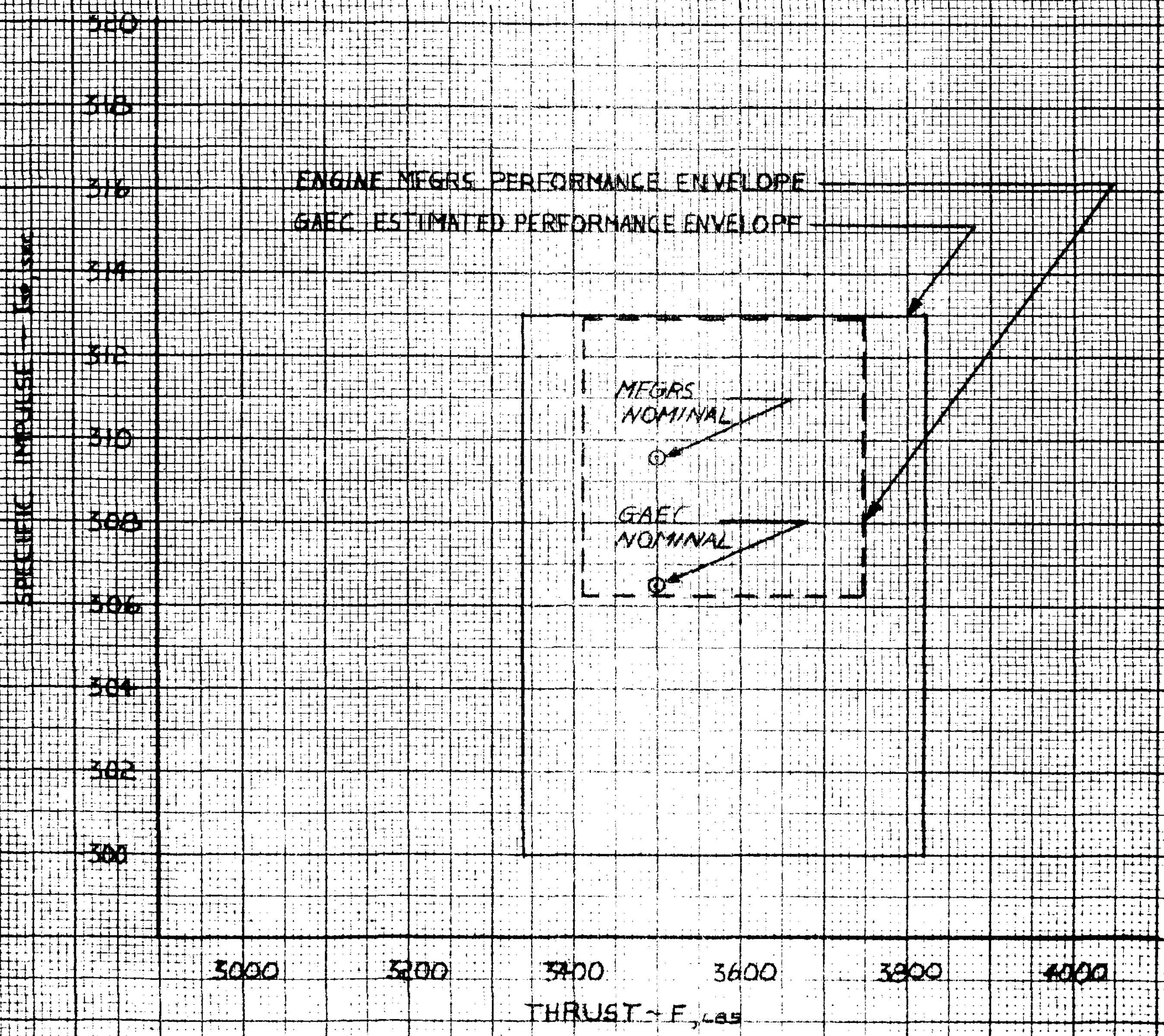
ESTIMATED PERFORMANCE ENVELOPE
FOR ASCENT STAGE

FIGURE 1

REFERENCE 3
GAEC LMO-271-5 23 July 1963



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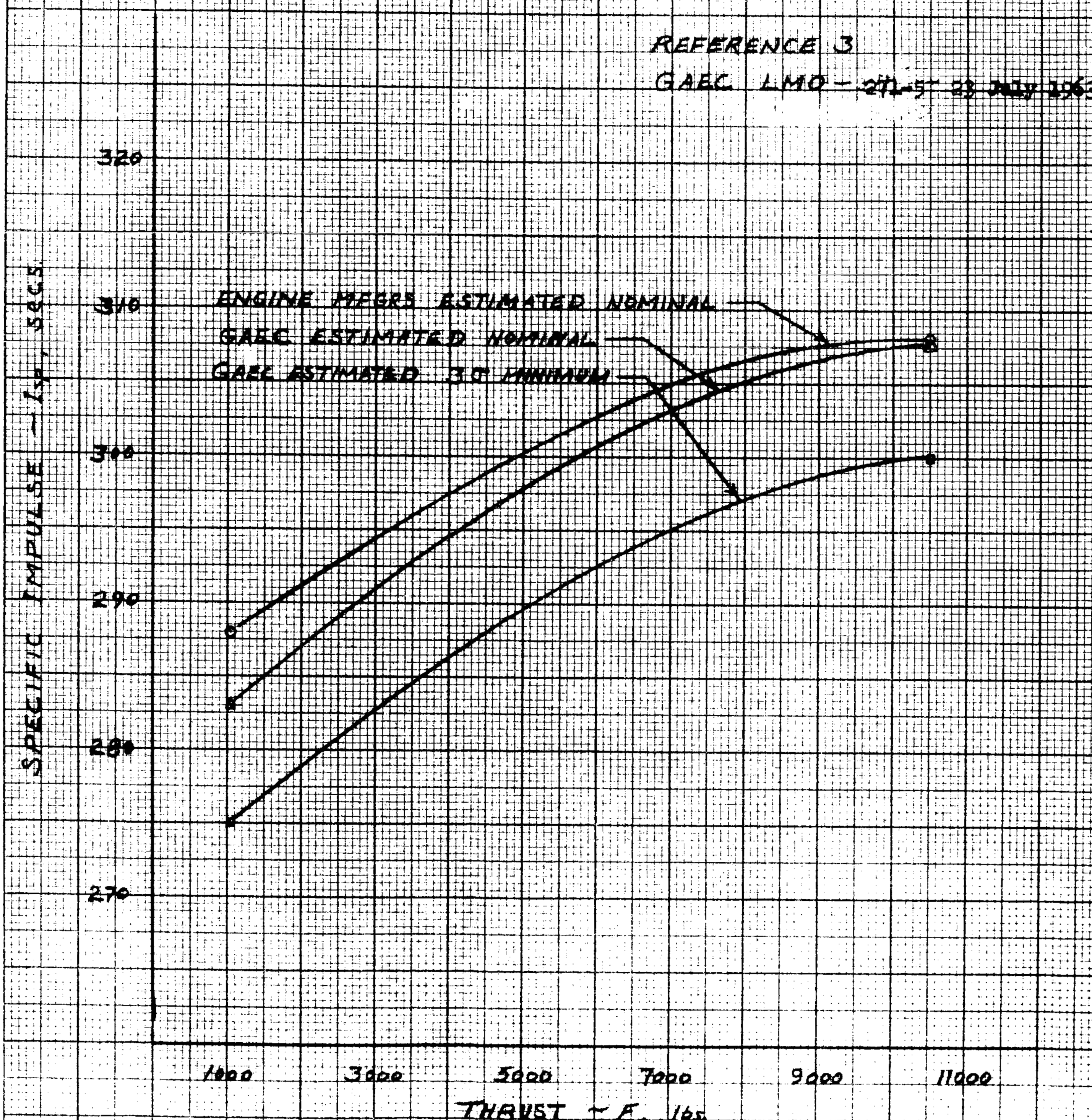
ESTIMATED PERFORMANCE OF DESCENT ENGINE TO BE USED FOR TRAJECTORY ANALYSIS AND TANK SIZING STUDIES

FIGURE 3

REFERENCE 3
GAEC LMO - 271-5 23 July 1963



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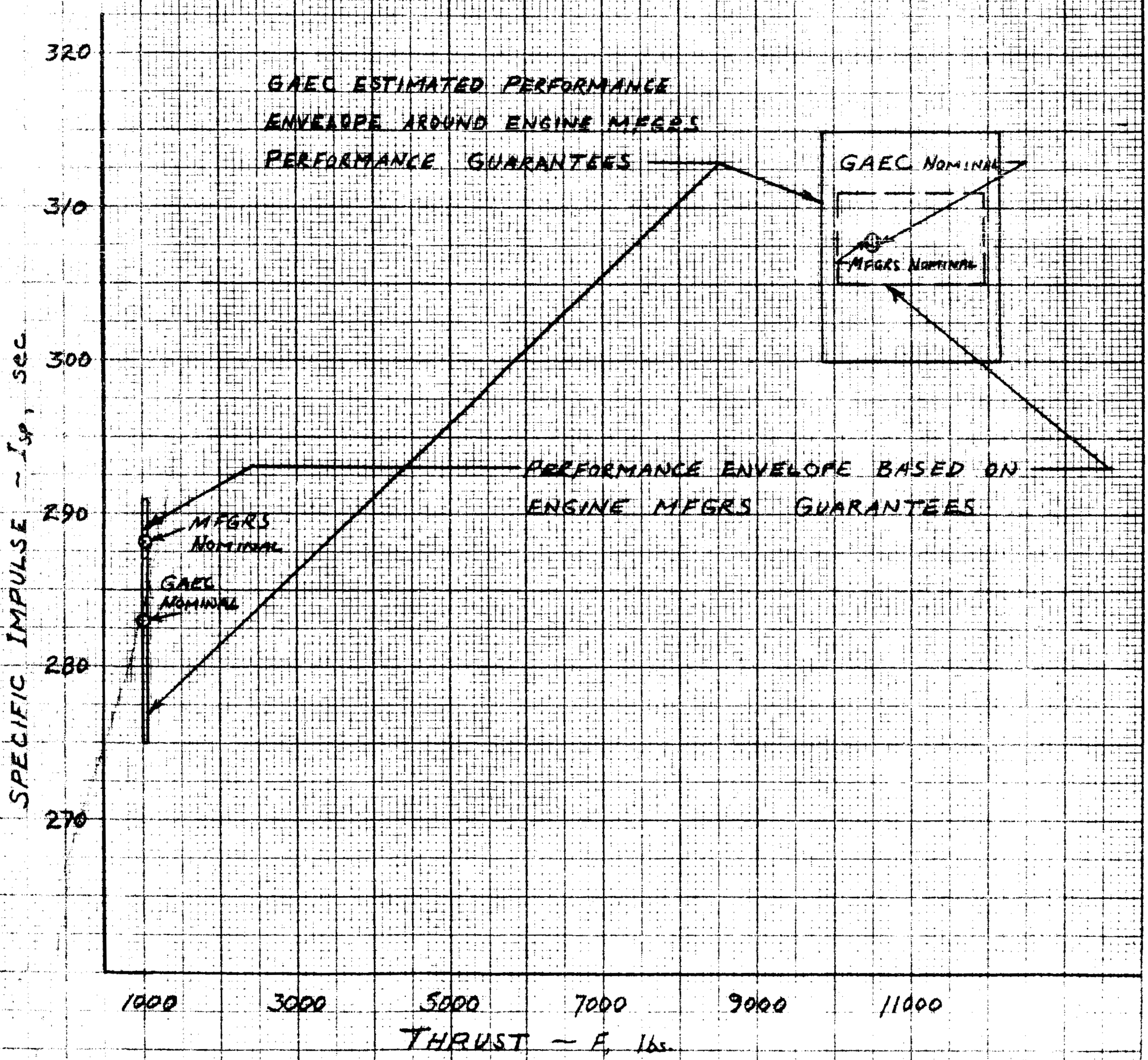
ESTIMATED PERFORMANCE ENVELOPE AROUND MINIMUM AND MAXIMUM THRUST LEVELS FOR DESCENT STAGE

FIGURE 4

REFERENCE 3
GAEC LMO-271-5 23 July 1963



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